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Atlas results on charmonium production and B_c^+ meson production and decays*

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Recent results from the proton-proton collision data taken by the ATLAS experiment on the charmonium production and on the B_c^+ meson production and decays are presented. The measurement of J/ψ meson and $\psi(2S)$ meson differential cross sections is reported. New results on the B_c^+ meson decays to $J/\psi D_s^{(*)}$ final states are included. Both studies are based on pp collision data collected at $\sqrt{s} = 13$ TeV during the LHC Run 2, corresponding to an integrated luminosity of 139 fb^{-1}. The measurement of the differential ratios of the B_c^+ and B^+ mesons production cross sections at $\sqrt{s} = 8$ TeV with an integrated luminosity of 20.3 fb^{-1} is also discussed.

Keywords: Charmonium; heavy flavour physics; ATLAS; LHC.

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1. Introduction

ATLAS [1] at the Large Hadron Collider (LHC) is a multi-purpose detector, designed to study a variety of physics phenomena. In heavy flavour physics, it is mainly focused on studying final states with two muons, due to the availability of corresponding triggers with relatively low muon thresholds. Heavy quarkonium states decaying to muon pairs represent a good object for studying heavy quark dynamics. However, despite the long history, the investigation of quarkonium production in hadronic collisions still represents significant challenges to both theory and experiment. The large amount of pp collision data collected by the LHC experiments opens new opportunities for precise measurements of the B_c^+ meson properties. These studies were limited before because of a low B_c^+ meson production cross section. Being the only weakly decaying meson consisting of two heavy quarks, the B_c^+ meson represents a unique testing ground for various theoretical approaches that are used to describe its production and decays. This proceeding overviews the recent measurements of charmonium production and B_c^+ meson properties performed with pp collision data collected at 8 and 13 TeV centre-of-mass energies.

2. Charmonium production measurement

Differential production cross section of J/ψ and $\psi(2\mathrm{S})$ mesons was measured by ATLAS using pp collision data collected at $\sqrt{s} = 13$ TeV corresponding to an integrated luminosity of 139 fb^{-1} [2]. The measurement aimed at high-p_{T} charmonium production, to benefit from using high-p_{T} single-muon triggers. The fixed-order next-to-leading-logarithm (FONLL) model calculations [3] within the framework of perturbative QCD have been reasonably successful in describing the non-prompt contributions, however, a satisfactory understanding of the prompt production mechanisms is still to be achieved. Prompt and non-prompt J/ψ and $\psi(2S)$ mesons production cross sections are measured in bins of the meson p_{T} and rapidity, as well as non-prompt fraction for both mesons and ratio between $\psi(2S)$ and J/ψ productions. The studied p_{T} range extends to 360 (140) GeV for J/ψ ($\psi(2S)$) meson. This is higher than in all other similar measurements to date.

Figure 1 shows a comparison of the measured non-prompt production cross sections to FONLL model expectation. The theory overestimates the data for J/ψ meson p_{T} above $100 - 150$ GeV while the agreement for $\psi(2S)$ meson is reasonable within the available precision.

3. B_c^+ meson measurements

With the $\sqrt{s} = 8$ TeV dataset ATLAS has measured [4] a relative B_c^+/B^+ meson production rate defined as:

$$\frac{\sigma(B_c^+)}{\sigma(B^+)} \times \frac{\mathcal{B}(B_c^+ \to J/\psi\pi^+)}{\mathcal{B}(B^+ \to J/\psi K^+)}.$$

The measurement is done inclusively in two bins of the meson p_{T} or rapidity. The relative production cross section for the inclusive region $p_{\mathrm{T}} > 13$ GeV and $|y| < 2.3$ is $(0.34 \pm 0.04(\mathrm{stat.})^{+0.06}_{-0.02}(\mathrm{syst.}) \pm 0.01(\mathrm{lifetime}))\%$. The results are shown in Fig. 2. The B_c^+ production cross section is found to decrease with p_{T} faster than that of the B^+ production while no significant dependence of the relative rate on the rapidity is seen. The ATLAS result is consistent with one obtained by CMS in a similar kinematic range at $\sqrt{s} = 7$ TeV and smaller than in the measurement of LHCb at lower p_{T} and higher rapidity (see Ref. [4]).

A new measurement of the branching fraction of the $B_c^+ \to J/\psi D_s^{(*)+}$ decays relative to the reference $B_c^+ \to J/\psi\pi^+$ decay channel was done in ATLAS with the full $\sqrt{s} = 13$ TeV dataset [5]. The purpose of this study is to improve the precision of measured properties of these decays by using a larger data sample and new analysis methods. The

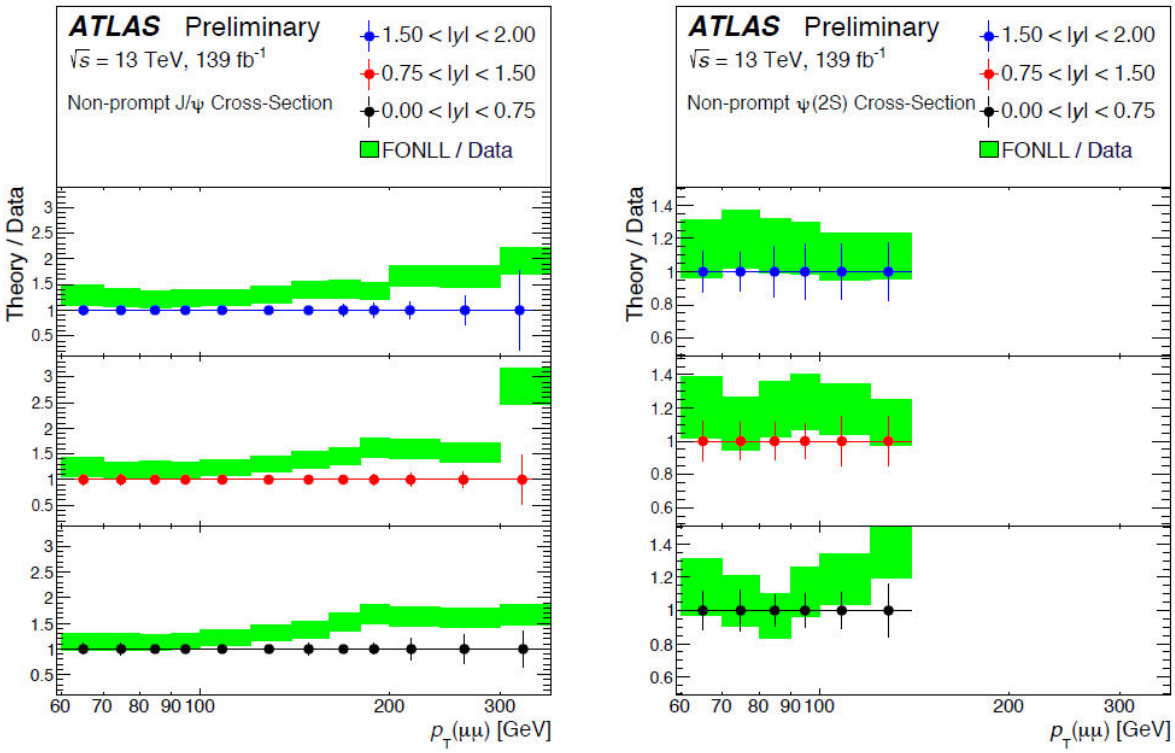

FIGURE 1. The ratios of the FONLL prediction to the measured differential cross sections for non-prompt J/ψ (left) and $\psi(2S)$ (right) mesons. The green shaded bands represent the range of theoretical uncertainty associated to the variations of the scales. Figure is taken from Ref. [2].

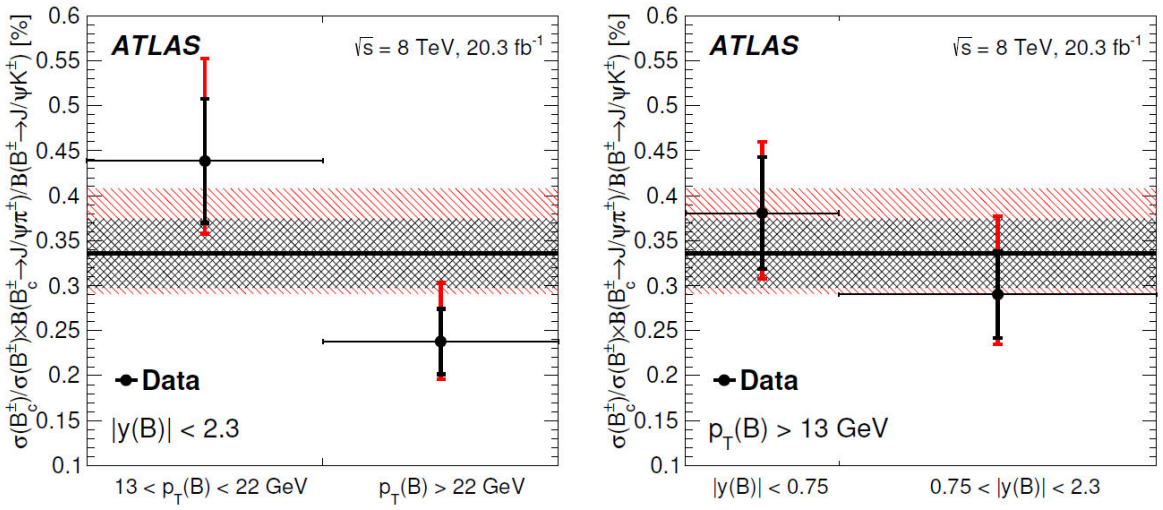

FIGURE 2. Production cross section for the B_c^+ relative to the B^+ (times the corresponding branching fractions) in two bins of p_T (left) and rapidity bins (right). Inner black (outer red) error bars show the statistical (total) uncertainty. For the inclusive bin, the horizontal black (red) bands show the statistical (total) uncertainty. Figure is taken from Ref. [4].

$B_c^+ \to J/\psi D_s^{(*)+}$ decay candidates are built by combining the selected J/ψ meson and $D_s^{(*)+}$ meson candidates. The J/ψ meson decays at the same point as the B_c^+ meson (secondary vertex) while the D_s^+ meson lives long enough to form a displaced tertiary vertex.

The D_s^+ meson is reconstructed via the $D_s^+ \to \phi\pi^+$ decay with the ϕ meson decaying into a pair of charged kaons. The D_s^{*+} meson decays into a D_s^+ meson and a soft photon or π^0 meson which are not reconstructed in the analysis. However, the mass difference between the D_s^{*+} and D_s^+ mesons is sufficient for the two decay signals to be resolved as two distinct structures in the distribution of reconstructed mass of $J/\psi D_s^+$ system. The J/ψ meson is reconstructed via its decay into a muon pair. The $B_c^+ \to J/\psi\pi^+$ decay is used as a reference to measure the branching fractions.

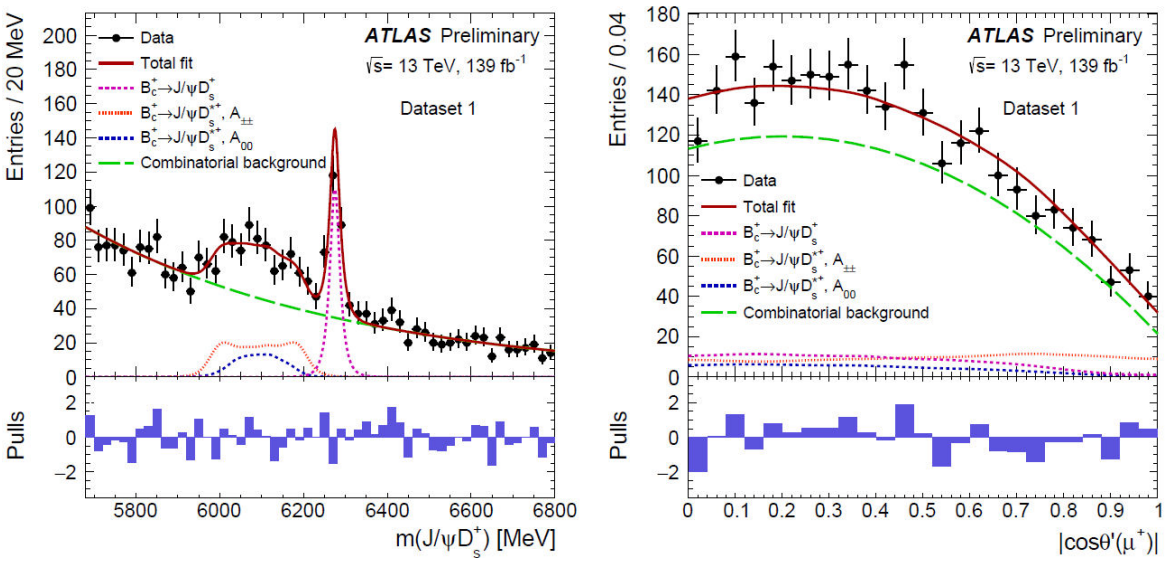

FIGURE 3. Distributions of the $J/\psi D_s^+$ system invariant mass (left) and absolute cosine of the J/ψ helicity angle (right) for the selected $J/\psi D_s^+$ candidates. The overall fit result is shown, as well as contributions of the $B_c^+ \to J/\psi D_s^+$ decay and different helicity components of $B_c^+ \to J/\psi D_s^{*+}$ decay signal. Figure is taken from Ref. [5].

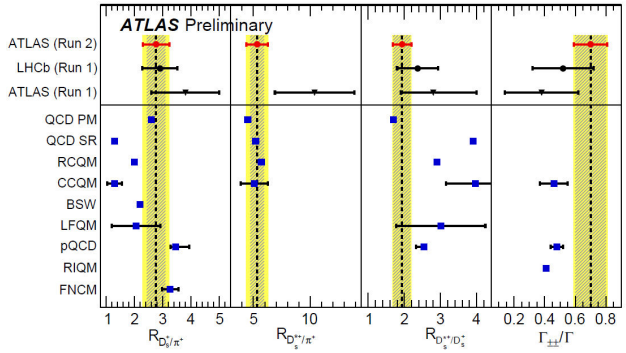

FIGURE 4. Comparison of the $B_c^+ \to J/\psi D_s^{(*)+}$ decay measurement results with those of ATLAS and LHCb Run 1 measurements and with various theoretical predictions (corresponding references can be found in Ref. [5]). Figure is taken from Ref. [5].

To extract the signal yields and helicity composition of the $B_c^+ \to J/\psi D_s^{*+}$ decay, distributions of $J/\psi D_s^+$ system invariant mass and the J/ψ helicity angle are exploited. Projections of the corresponding 2D fit are shown in Fig. 3.

Three ratios of branching fractions and the fraction of transverse polarization in the $B_c^+ \to J/\psi D_s^{*+}$ decay are measured. The ratios between the branching fractions for $B_c^+ \to J/\psi D_s^{(*)+}$ and $B_c^+ \to J/\psi \pi^+$ decays are found to be

$$R_{D_s^+/\pi^+} = 2.76 \pm 0.33(\text{stat.}) \pm 0.29(\text{syst.}) \pm 0.16(D_s),^{i} \quad (1)$$

$$R_{D_s^{*+}/\pi^+} = 5.33 \pm 0.61(\text{stat.}) \pm 0.67(\text{syst.}) \pm 0.32(D_s). \quad (2)$$

The ratio between the branching fractions for $B_c^+ \to J/\psi D_s^{*+}$ and $B_c^+ \to J/\psi D_s^+$ decays is found to be

$$R_{D_s^{*+}/D_s^+} = 1.93 \pm 0.24(\text{stat.}) \pm 0.10(\text{syst.}). \quad (3)$$

The fraction of transverse polarization in $B_c^+ \to J/\psi D_s^{*+}$ decay is found to be

$$\Gamma_{\pm\pm}/\Gamma = 0.70 \pm 0.10(\text{stat.}) \pm 0.04(\text{syst.}). \quad (4)$$

Measurements are summarized in Fig. 4, in comparison with results of earlier ATLAS and LHCb measurements done with $\sqrt{s} = 7, 8$ TeV data and with relevant theory predictions. The precision of all measured quantities exceeds that in the earlier studies. Consistency of the predictions for the branching fraction ratios with data varies between the used approaches. It is worth pointing out though that the measured value of $\Gamma_{\pm\pm}/\Gamma$ agrees with the value of 2/3 expected from naive spin-counting considerations, while the dedicated calculations yield values noticeably below data.

4. Summary

The recent ATLAS results in heavy flavour physics, including studies of charmonium production and B_c^+ production and decay were highlighted in this contribution. They are obtained with the data collected by LHC during Run 1 and Run 2, corresponding to integrated luminosities 20.3 fb^{-1} and 139 fb^{-1} respectively. These results are compared to theoretical predictions and can serve as probes for the available models.

i. The uncertainty on the branching fraction of $D_s^+ \to \phi(K^+K^-)\pi^+$ decay.

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